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The 1982 Morning Glory Expedition

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Die Morning Glory-Expedition von 1982

Summary. Morning Glories — wind squalls accompanied by spectacular roll clouds — are observed quite regularly (especially in October) around the Gulf of Carpentaria in Northern Queensland, Australia. This article gives a short introduction to the phenomenon itself, reports the activities during the last expedition (11th to 25th October 1982) and presents first results, such as streamlines and horizontal wind components in a frame of reference moving with the glory.

Zusammenfassung. Morning Glories — Böenlinien, die von sehr eindrucksvollen Rollenwolken begleitet werden — sind ziemlich regelmäßig (vor allem im Oktober) am Golf von Carpentaria in Nordqueensland, Australien, zu beobachten. Dieser Bericht gibt eine kurze Einführung zum Phänomen als solchem, beschreibt die Tätigkeiten während der letzten Expedition (11.—25. Oktober 1982) und stellt erste Ergebnisse vor, wie zum Beispiel Stromlinien und Komponenten des Horizontalwinds in einem Bezugssystem, das sich mit der Glory bewegt.

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1. Introduction

Morning glory is the local name for a long, straight roll cloud — or several in succession — which occurs early in the morning around the southern coast of the Gulf of Carpentaria in northern Australia. Some are spectacularly illuminated by the rising sun, this being the origin of the name. The clouds move across the sky in a direction normal to their length at a speed of about 10 m/s.

In recent years the morning glory has attracted the interest of fluid dynamicists as an atmospheric kind of undular bore (see e.g. [6, 7, 11]). The term "undular bore" denotes a wave train like type of elevation at an interface of fluids. Most prominent are the undular bores which occasionally are excited by the tides in the Bristol Channel and which travel up the river Severn for long distances. An important feature of those bores is, that the interface behind them lies at a higher level than in front of them. In the lower atmosphere a sharp inversion between very stable air in the ground layer and less stable air above constitutes the analogy to the „classical" interface between water and air. One should note that this analogy is far from perfect, mainly due to the complicated internal structure of the atmosphere as a stratified and sheared environment (see [6] for details and further references).

At the same time morning glories exhibit characteristics of solitary waves that travel in the lower atmosphere, trapped by an inversion. Solitary waves are defined as single crested waves of permanent form which propagate in horizontal waveguides (see e.g. [3]).

It appears that the morning glory of the gulf of Carpentaria has to be regarded as a rather pure type of undular bore which can develop and travel quite undisturbed over the flat coastal plains and the gulf itself and — most important — which is marked by clouds. Those are permanently formed as air is lifted by the wave in the humid maritime boundary layer and subsequently they disappear because of subsiding motion at the wave's trailing edge.

References to the phenomenon date back to the late 1930's [4]. Neal et al. give a first systematic overview based on the sparse observational data available then [9]. In 1979, 1980 and 1981 small expeditions were organized to collect more specific data both on the surface and in the lower atmosphere up to about 2 km. The results are documented in several papers [7, 10, 11]. Very recently Clarke published a twin paper on wind surges and atmospheric

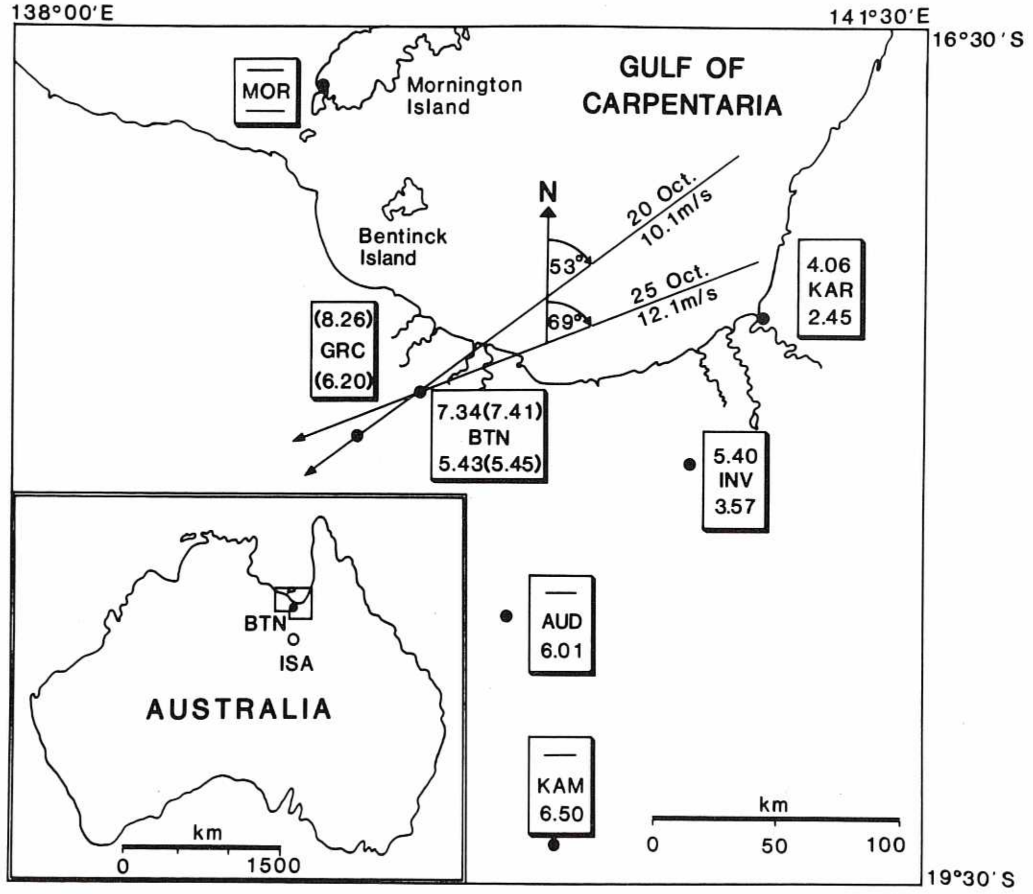

Fig. 1. Map of the southeastern corner of the Gulf of Carpentaria with anemograph stations and times of discontinuities in the records due to morning glory passages (for 20 Oct. above names, for 25 Oct. below; in brackets for pressure jumps). The small map shows the relative situation within Australia. Abbreviations: AUD = Augustus Downs, BTN = Burketown, GRC = Gregory Crossing, INV = Inverleigh, ISA = Mt. Isa, KAM = Kamileroi, KAR = Karumba, MOR = Mornington Island.

bores [5, 6], part two of which compiles the latest results of the campaigns in 1980 and 1981.

Parallel to these efforts several theoretical studies were undertaken. Clarke uses a numerical model and classifies the morning glory as a hydraulic jump [4]. Later he and his co-workers try to describe their observational data [7] with Benjamin's model [1]. Most recently Egger extends that model by a dissipative mechanism and solves the resulting viscous „Korteweg-deVries equation" in parameter space [8].

It is thought that most morning glories originate somewhere over the western side of Cape York peninula ([6, 7]; see Fig. 1). Presumably they are generated by the interaction of sea breeze fronts (coming inland from the west *and* east coast of the peninsula) with a developing nocturnal inversion. They travel during night time over the southern part of the Gulf and the adjacent coastal flats in a roughly southwesterly direction. After leaving the Gulf, sometime in the morning, the clouds may dissolve some distance inland, but pressure disturbances propagate further.

At the end of the 1979 expedition a squall with roll clouds was observed coming from the south, much to the surprise of the expedition's members. During the observation periods in the following years several southerly morning glories appeared with much the same characteristics and time of arrival, but with so far little understood origin [11]. Photographs taken by B. O'Brien, the school teacher at Burketown, show the unique feature of a northwesterly and a southerly morning glory cloud line intersecting on one morning in September 1982 (see also [3], p. 180).

One of the best places for the observation of morning glories is Burketown, an isolated township 30 km off the southern cost of the Gulf of Carpentaria on the extremely thinly populated coastal flats (see Fig. 1; it is interesting to note that the Shire of Burke around Burketown has 1/6 the area of West Germany with a population of less than 1000). Both types of morning glories arrive there mainly between 06.00 and 09.00 EST[1] and thus can be observed in daylight.

The last expedition took place from 11 to 25 October 1982 with ten participants from different institutions; this paper reports on the activities carried out. Independently Christie and Muirhead recorded solitary-wave-dominated disturbances in the Burketown area on a microbarometer network. The results were recently published [3] and agree well with our findings discussed in section 3.

The remainder of this article is divided into three sections. The first describes the kind of observations carried out and the events that occurred. In the following chapter typical results are discussed and finally conclusions are attempted towards the value of these kinds of field measurements.

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[1] All times are quoted in "Eastern Australian Standard Time", equal to GMT + 10 h.

Fig. 2. Shallow cloud band of morning glory and "optical observers"; 20 October, 07.15.

2. The 1982 expedition

The purpose of the expedition was twofold. First, morning glory events should be documented in order to enlarge the data set obtained from three previous campaigns. Additionally, the experience from those earlier efforts was used as guide for an effective experimental set up with the limited resources that were available.

The determination of the atmospheric flow up to a height of two kilometers before, during and after a morning glory constitutes the main goal. This was achieved by tracking pilot balloons ("pibals") with two theodolites. To gain good time resolution two tracking teams operated which could observe different balloons released at staggered intervals of less than 10 minutes.

Fig. 3. Morning glory of 25 October 1982, observed 25 km SE of Burketown: a) first roll, 06.15; b) second roll, 06.20 — Note the laminar (a) and turbulent (b) type of airflow, as revealed by the different cloud surfaces.

Time series of pressure and surface winds, respectively, at the ground contain further important information. They were measured by a sensitive digital barometer and a Woelffle anemograph. A thermodynamic sounding of the pre-glory atmosphere is essential for a meaningful interpretation of the results. This was achieved by a radiosonde ascent at about 05.45 every morning. Further more photographs and time lapse films had proven to be an invaluable tool for documenting the cloud formations of a morning glory. So considerable camera equipment was used (see Fig. 2).

Besides these different observational systems, which are all situated at a single location, a temporary network of anemographs has to be installed in the further environment (characteristic length scale 100 km). Typical changes in windspeed and direction mark the time of passage of a glory and so its speed and orientation can be reconstructed (see section 3).

The ten members of the expedition and all the necessary equipment arrived at Mount Isa airport on 10 October in the morning. The first task was to deploy the anemographs at the few populated sites in the region (mainly cattle stations; see Fig. 1) and to carry all the other instruments to Burketown.

Unfortunately the synoptic pressure field was not favourable for the excitation of morning glories for large portions of the following fortnight. Nevertheless two remarkable events occurred, one on 20 October and the other five days later. A description of both follows.

In the early morning of 20 October dew on the cars gave the first hint, that the air was quite moist, a prerequisite for cloud formations in connection with a travelling disturbance. During the afternoon before a steady sea breeze had carried humid air inland. After the second pibal ascent the sun rose, giving the sky that light blue appearance which we knew so well from all the previous mornings. No cloud was to be seen, only shallow layers of mist streched over the northeastern horizon.

Then, at about 06.30 a narrow band of cloud was discernible, slowly rising from the horizon and apparently moving towards us. From experience we knew that it would take approximately one hour till the first squall would come overhead, ample time to be prepared. Further balloons were released, readings from the digital barometer were made every half minute and still and movie cameras awaited the cloud line (see Fig. 2). It was fascinating to observe its immense lateral extent when it came closer. But then we began to realize that the humidity as far inland as Burketown was not sufficient for the continued formation of cloud. The thin roll gradually dissolved before it came overhead and so did the broken lines following it. Although thus not being very spectacular for the eye, the disturbance travelled on and gave us the unique chance to track balloons, released in short time intervals up to heights of about 2.5 km, without being lost in cloud.

At 07.42 a pressure jump of 0.8 mbar within 4 minutes (see Fig. 4) followed strong gusts which set in some minutes earlier — indications of the passage of the disturbance. The anemograph displayed a change from a light southeasterly (1 m/s) to a stronger northeasterly (5 m/s) wind (see Fig. 5).

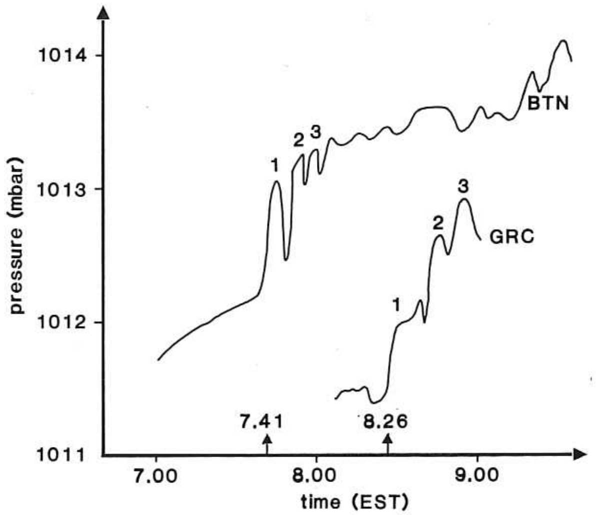

Fig. 4. Pressure traces with onset times of jumps from Burketown (BTN) and Gregory Crossing (GRC), 20 October.

By 10 o'clock 19 pibal ascents had been carried out as well as the routine radiosonde ascent at 05.45. Two pressure traces were obtained also, one at the baseline and one at Gregory Crossing, 27 km to the southwest where one of the team had chased the disturbance.

On the afternoon of the 24th, impressive convective systems built up further inland and in the evening a long, broad band of cloud streched over Burketown, nicely illuminated by the setting sun. So moisture was obviously around and the question arose, whether the atmosphere would show us an impressive morning glory on our very last day.

In the morning, light dew on the cars gave again the first hint. When the theodolites were set up, we recognized in the first twilight a really tremendous morning glory. A very smooth, greyish wall of cloud of high vertical extent (at least 2 km) stood before us, with ends mixed indiscernibly with the black sky on either side. We realized with some horror that the leading edge was less than 15 minutes away, so it was unlikely that we would get a balloon aloft in the undisturbed air prior to the disturbance and it would be impossible to obtain reasonable photographic documentation because of the poor light conditions. Therefore three of the team dismantled all the camera gear, put it in one car and rushed down the road to Gregory Crossing to gain half an hour during which time the sun would rise. There they were able to obtain instructive photographs (e.g. Fig. 3) and two time lapse films — besides a pressure trace — of the seven cloud bands of gradually decreasing size that passes overhead. The rest of the team released two radiosondes and a series of nine balloons — the first of which was unfortunately only after the passage of the first squall.

Because of its size this morning glory is resolved by the NOAA 7 satellite. The picture obtained from the infrared channel at 02.45 clearly displays cloud lines over the southern part of the Gulf (approximately over KAR with an orientation 340°/160°; this is in good agreement with the findings from the ground [see Fig. 1]).

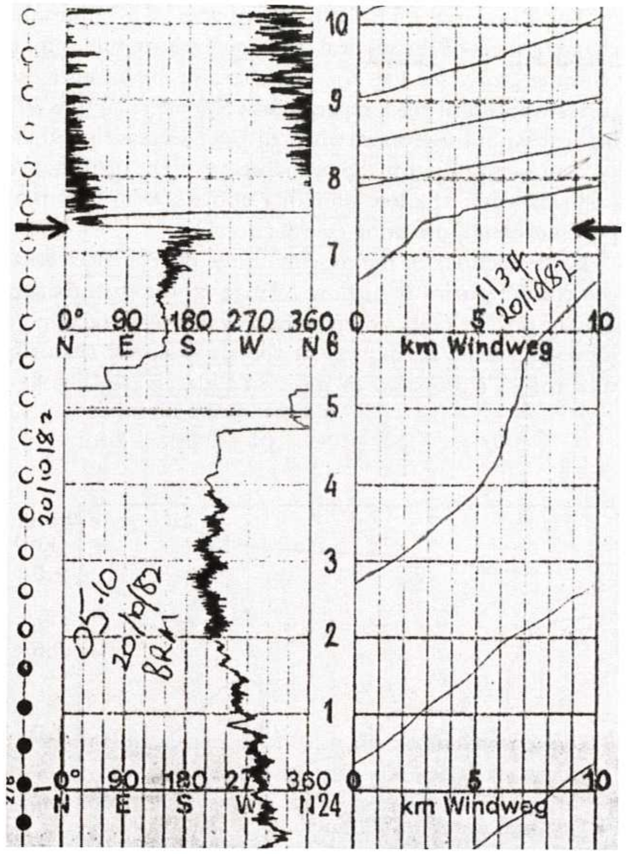

Fig. 5. Anemograph registration from Burketown, 20 October. The abrupt change in wind direction and in wind speed (calculated from "run of the wind" [Windweg] per unit of time) indicates the passage of a disturbance at 07.42 (marked by arrows; note that time scaling is 12 minutes slow).

Besides the events mentioned above one event without cloud was detected on 15 October at about 07.00 by sudden gusts and a slight pressure jump. On 26 October, the day of our departure from Burketown, a strong glory passed at the exceptional early time of 04.30, so that there was no change to carry through measurements which need daylight.

Christie and Muirhead ([3], Fig. 8) show micropressure amplitudes observed in the Burketown area during the whole of October 1982. Besides 30 events without clouds they mention five with clouds just before or after our observational period. For 24 October (at about 07.00) a morning glory with clouds is given in their table — this in contradiction with our observations.

In the next section we present results from the data obtained on the 20th and on the 25th.

3. Results

On the presumption that morning glories are atmospheric undular bores which move as straight wave fronts with constant speed a coordinate system with origin fixed at the first squall is appropriate to study the airflow relative to the disturbance. The x direction points normal to the squall (rearwards) and y is measured at right angles along the squall (see Fig. 7).

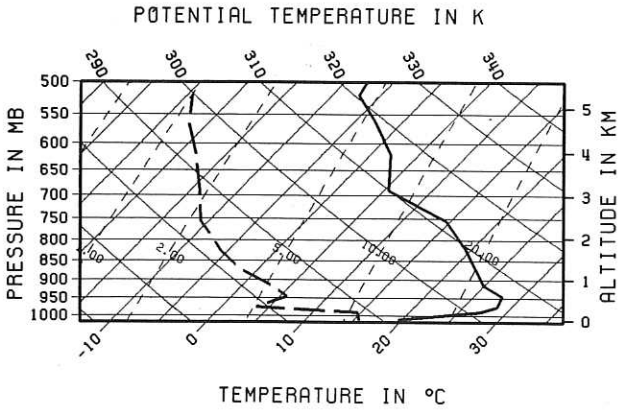

Fig. 6. Vertical profile of temperature (—) and dew point (----); Burketown, 20 October, 05.45 (skew T/log p - diagram).

Thus point observations in the geographic system at different times t (relative to the onset time of the first squall τ) constitute a spatial cross section relative to the glory. Offset angle θ and propagation speed c are determiend from passage times at several different locations via a least square fit. At additional anemograph locations the differences between the predicted and observed times of passage are small (e.g. in the order of minutes). So the "straight line — uniform speed" assumption appears to hold well[2].

Fig. 1 shows times of passage (determined from anemograph records in BTN, AUD, KAM, INV, KAR and from pressure traces in BTN and GRC) for the 20th and the 25th. The latter event is of wide lateral extent displaying discontinuities as far south as KAM, while the former glory shows up only in the registrations from KAR, INV and BTN. But its speed and orientation are well confirmed by the pressure jump's time lag between BTN and GRC. The results

Date	θ	c
20/10/82	53°	10.1 m/s
25/10/82	69°	12.1 m/s

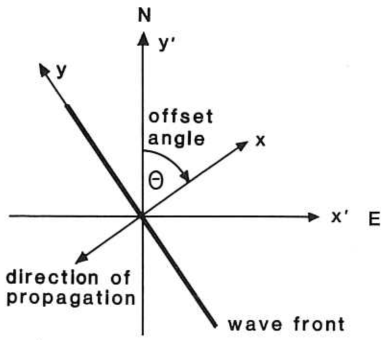

Fig. 7. Coordinate systems — geographic (x', y') and rotated (x, y).

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[2] A striking example for the validity of this assumption over 500 km is given in [5], Fig. 1.

are also indicated in Fig. 1. As pibal data with good time resolution are only available for the 20th, the following discussion is restricted to that event.

The pressure traces obtained in BTN and GRC on the 20th illustrate the detailed complexity of the phenomenon (see Fig. 4). Three distinct waves with decreasing amplitudes passed both sites, although their shape is quite different. Nevertheless, size and duration of the pressure jumps for the first two waves are similar (BTN: 0.8 mbar/4 min and 0.8 mbar/6 min; GRC: 0.6 mbar/5 min and 0.7 mbar/5 min). The difference in mean pressure between the two sites (0.8 mbar) is equivalent to a height difference of 7 m (at 22 °C), a figure confirmed by the most accurate maps available.

The Burketown TEMP demonstrates two important characteristics of the vertical atmospheric structure prior a morning glory (see Fig. 6). The sharp inversion near the surface (note that the temperature at 500 m [950 mb] is 8 K higher than at the ground) with a distinct decrease in stability is a prerequisite for the propagation of the disturbance (see [7]), while the low humidity above 200 m (990 mb) prevents cloud formation (see Section 2).

Cross sections in the moving frame of reference reveal the characteristics of airflow relative to the disturbance. The normal velocity component u is positive everywhere indicating that the motion of the air is slower than the disturbance's propagation speed in all levels (see Fig. 8a).

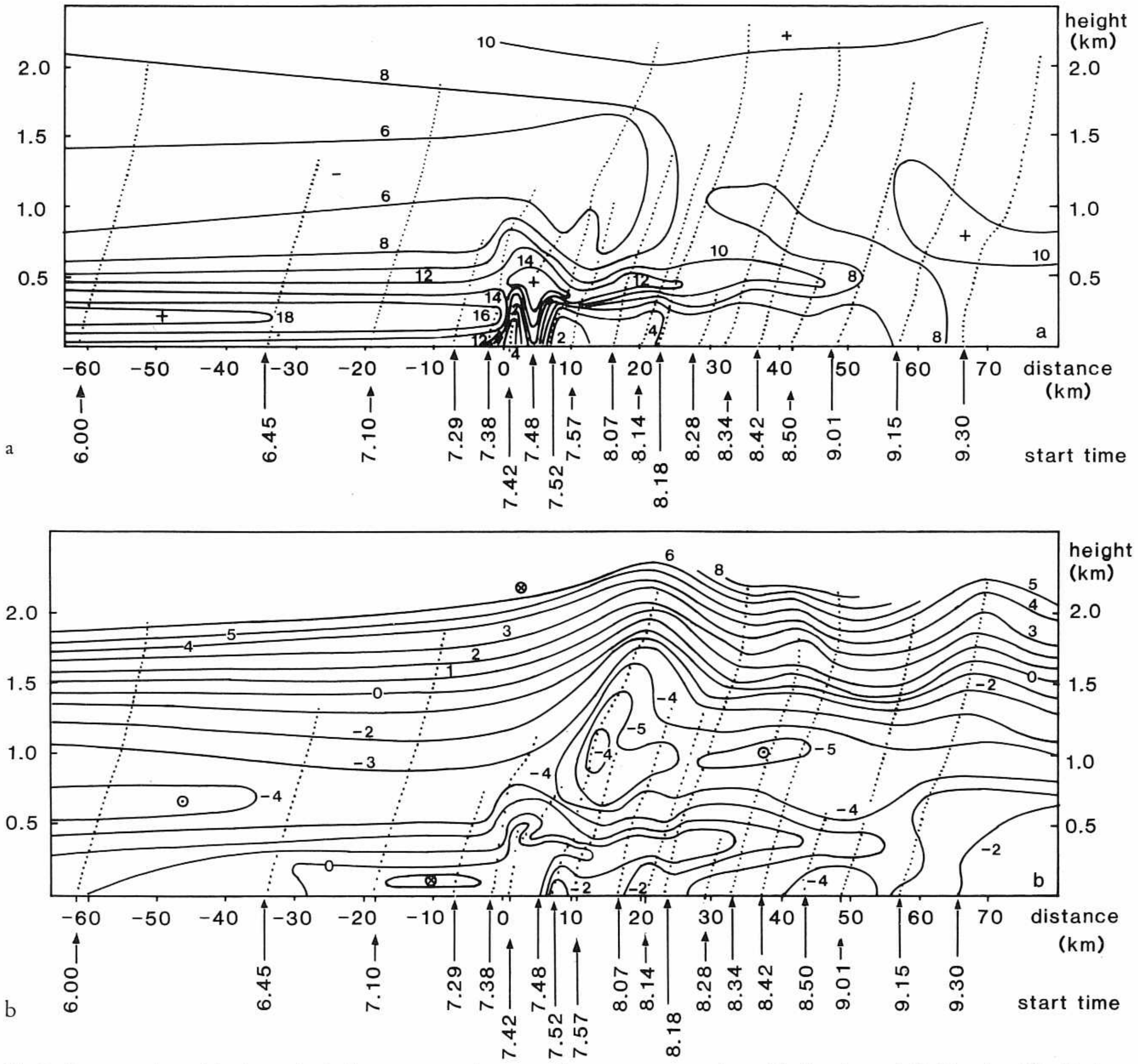

Fig 8. Cross section of horizontal wind components in a coordinate system moving with the glory of 20 Oct. (see Fig. 7; dots indicate mean height between observed balloon positions, where velocities are evaluated by central differencing). a) normal or (u—c)-component, b) lateral or v-component (in m/s).

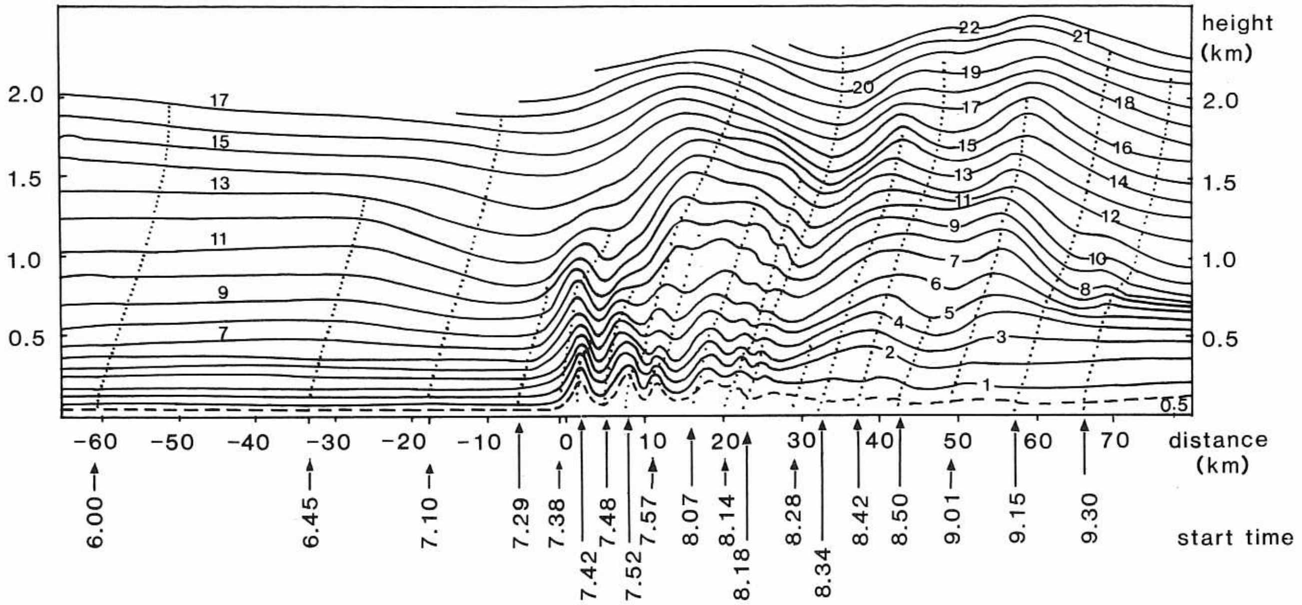

Fig. 9. Cross section of relative streamfunction ψ (in 10^3 m²/s²); coordinate system as in Fig. 8 (dots indicate observed balloon positions).

The pre-glory situation (x<0) is characterized by a smooth field of horizontal isotachs with the speed maximum at about 200 m and a layer of minimum speed between 1000 m and 1500 m. From the glory's onset (x=0) to 10 km to its rear, a wavy pattern of strong horizontal gradients within the lowest 300 m displays the small scale nature of the disturbance. Further behind ($x > 30$ km) the normal velocity is horizontally more uniform again; at about 400 m its values resemble those ahead the glory, below (above) that level they are considerably decreased (increased).

Fig. 8b shows that the air flow posesses a non-negligible lateral component v. Again the pre-glory field exhibits quasi horizontal isotachs with a change of sign at 1400 m. Below, the wind has a component towards SE (v<0; see Fig. 7), above one towards NW (v>0). About the time of the squall's onset a region of positive v is found at low levels. Ten kilometres behind the maximum SE-bound values ($v < -5$ m/s) are located underneath a distinct wave in the isotach pattern. In the further rear (x>20 km) the lateral velocity compoment first increases horizontally and then decreases at lower levels, while a more uniform, though somewhat wavy isotach pattern with a pronounced vertical gradient is predominant at higher levels.

For visualizing the airflow itself, a cross section of the relative streamfunction ψ is an adequate tool. The definition for the discretized increment

$$\Delta\psi = \frac{\partial\psi}{\partial z}\,\Delta z + \frac{\partial\psi}{\partial x}\,\Delta x$$

reduces to the simple relation

$$\Delta\psi = u\,W\,\Delta t$$

when some definitions (≡) and assumptions (=) are taken into account:

$$\partial\psi/\partial z \equiv u = u_B - c, \qquad u_B \equiv \Delta x/\Delta t$$

$$\partial\psi/\partial x \equiv w = w_B - w, \qquad w_B \equiv \Delta z/\Delta t$$

Here u and w indicate the velocity components of the air flow (no index) and the ballon (index B), respectively, W the balloon's ascent rate in still air, c the uniform speed of the disturbance and Δx and Δz the balloon's position increments in x- and z-direction per time step Δt (normally 30 s). The stream-function values at a specific height result from summation over Δψ from the ground ($\psi \equiv 0$) to that level.

Fig. 9 shows the relative streamline structure. Horizontal isohypses with a vertical decreasing gradient characterize the pre-glory field. The foot of a first wave with its top at abount 1000 m and with a vertical axis (vertical displacement ca. 300 m) lies at the onset of the disturbance (x=0). Five waves of different amplitude and horizontal width follow below the level of 500 m. In higher altitudes slight descending motion occurs ahead of the glory and the waves behind it have greater lateral extent. These findings are in agreement with recent theoretical studies [8].

Although the lack of data at heights above 1000 m (for $-8\text{ km} < x < 12\text{ km}$) makes it impossible to assess the vertical extent of the first waves precisely, the morning glory of 20/10/1982 is classified as a shallow event (compared e.g. with the one of 4/10/1979; see [7], Fig. 13). Only streamlines with ψ less than $5 \cdot 10^3$ m²s⁻¹ exhibit the characteristic for bores, namely greater elevation behind the disturbance (ca. 250 m) than ahead of it. At higher levels the streamlines are certainly influenced by the disturbance, but not in such a systematic way. The low and thin cloud (see Fig. 2), which dissolved approx. 20 km NE of Burketown, is an additional hint for the shallowness of the event.

As far as we are aware, the data set for the 20/10/1982 is unprecendented in duration (3.5 hours) and resolution (19 ascents; 450 data points[3]). The analyses (Figs. 8 and 9) show clearly the necessity of an even and dense distribution of data points for the detection of the small scale structures connected with a morning glory and for meaningful comparisons of the pre-glory and the post-glory situation.

4. Conclusions

The preceding sections give an account of the activities during the 1982 morning glory expedition and present first results from one well documented event. What conclusions can be drawn?

First there is the banal experience that the atmosphere is a random laboratory. Although it produced in 1982 the desired flows in the time known as the peak season [9], it is (apparently) possible to observe only two major events within 16 days, while several others happen just before and after the expedition period.

Although due to transport problems and expense only rudimentary equipment is used, data of good quality are obtained. In situ data processing (though in a preliminary and mostly manual way) proves to be very important, especially as a continual check of the instruments, which of course are no new insights.

The observed events are similar to the ones documented during the earlier campaigns. Nevertheless the time resolution of the series of ascents on 20 October is unprecedented; this was aided by the clouds' dissolution before they came overhead. Events such as the double morning glory from different directions (reported and photographed by local people) seem to be too rare that they can be measured other than on a routine — or very lucky — basis.

The material collected during the four expeditions covers a variety of morning glories; from the northwest and from the south, with tremendous cloud formations and with dissolving clouds or none at all. Although networks and sensors are not homogeneous through the years (partly light aeroplanes, partly radiosondes; different ground stations etc.) it may be possible to produce a rough climatology of morning glories and to study the synoptic and mesoscale characteristics of the lower atmosphere conducive to the generation and propagation of these disturbances. Then the limits of modest field experiments (as described in section 2 for 1982 — organized mainly by one university group!) will be reached.

Apparently morning glories are a pure and frequent form of atmospheric waves which exhibit characteristics of solitary waves and undular bores. Similar varieties occur in other areas as well (see [2] and [11] for further references; Stilke reports on wavelike disturbances over northern Germany [12]). If the results obtained from all the data collected so far indicate that morning glories are of general interest for mesoscale meteorology, more ambitious experiments would be appropriate. They then should incorporate different aircraft and/or remote sensing techniques (e.g. acoustic sounders, VHF radars) for the four dimensional probing of the atmosphere around the Gulf of Carpentaria. Additionally supposed mechanism in the physics and dynamics of the phenomenon have to be checked by controlled numerical experiments with a non-hydrostatic mesoscale model, as suggested by Clarke [6].

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[3] compared to e.g. 2.2 hours and 9 ascents on 4 October 1979.

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